Effective radiative forcing and rapid adjustments of contrail cirrus

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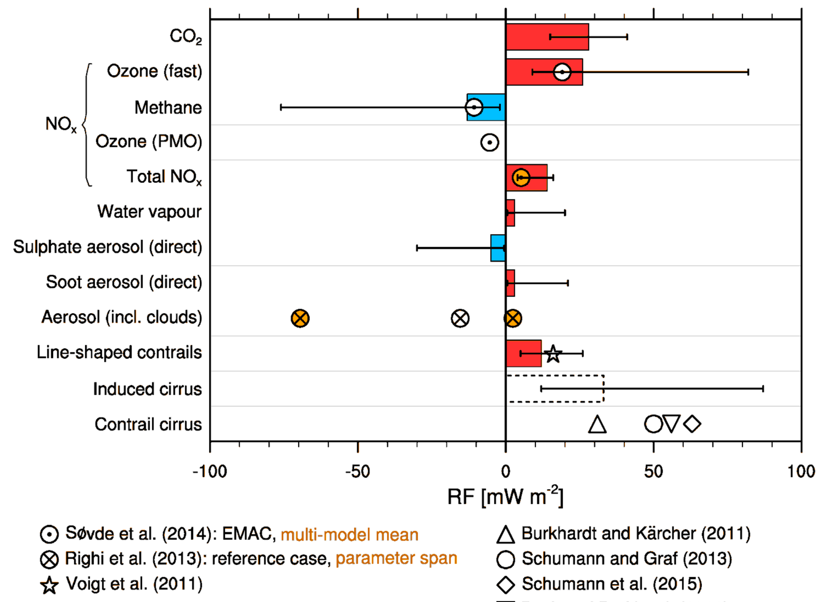
Climate Impact of Air Traffic

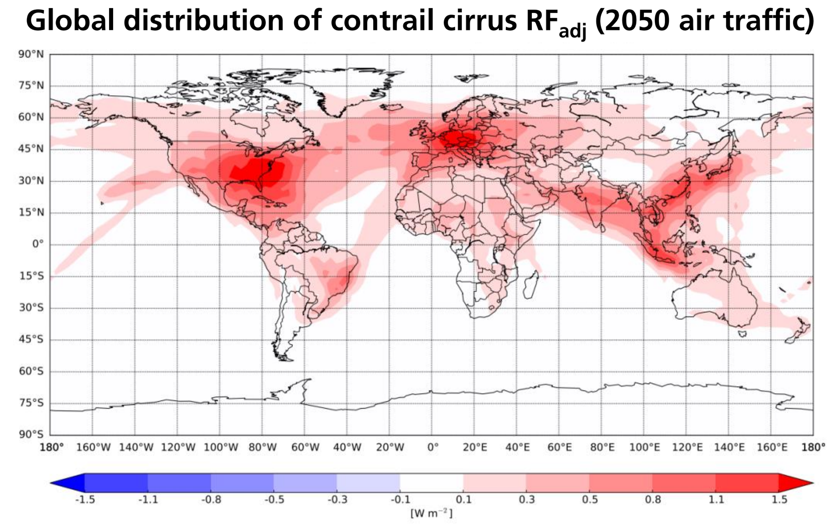


Grewe et al. (2017)

Air traffic affects the global climate mainly through contrails, CO_2 and NO_X emissions. The relevance of the individual contributions is expressed in terms of radiative forcing (RF). Overall contrail cirrus is regarded to be the largest contributor to aviation induced radiative forcing (Burkhardt and Kärcher, 2011). Contrail cirrus develops from line-shaped contrails which spread over large areas when the ambient air is cold and humid enough.

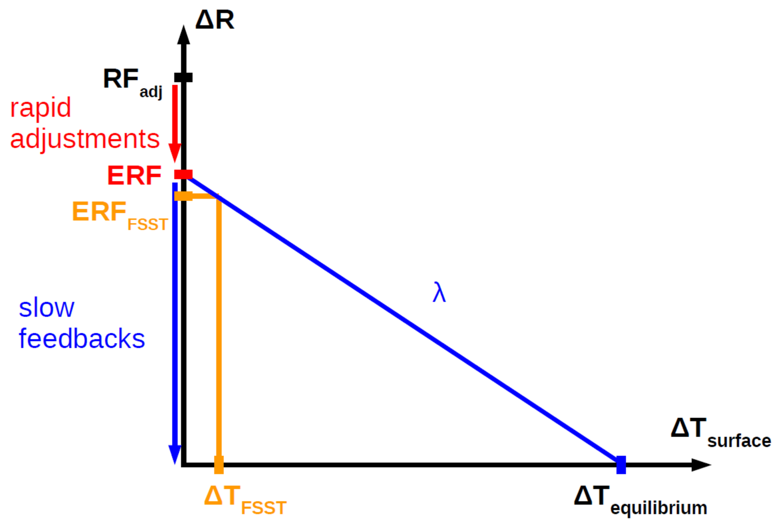
Air traffic is expected to grow exponentially for the coming years and thus plays an important role in future mitigation strategies. The climate impact of air traffic is a quite local phenomena and is largely correlated with air traffic density. A global mean adjusted radiative forcing (RF_{adj}) of 169 mWm^{-2} was calculated, based on the AEDT air traffic inventory for the year 2050. Locally, e. g. over the USA, Europe or parts of Asia, the RF_{adj} can reach values of up to 1.5 Wm^{-2}.

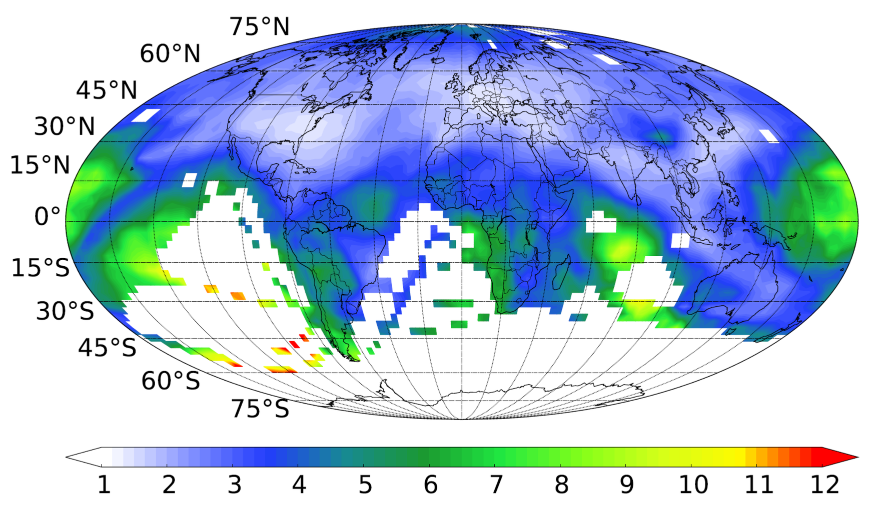
Global distribution of contrail cirrus RF_{adj} (2050 air traffic)



Reduced Efficacy of Contrails

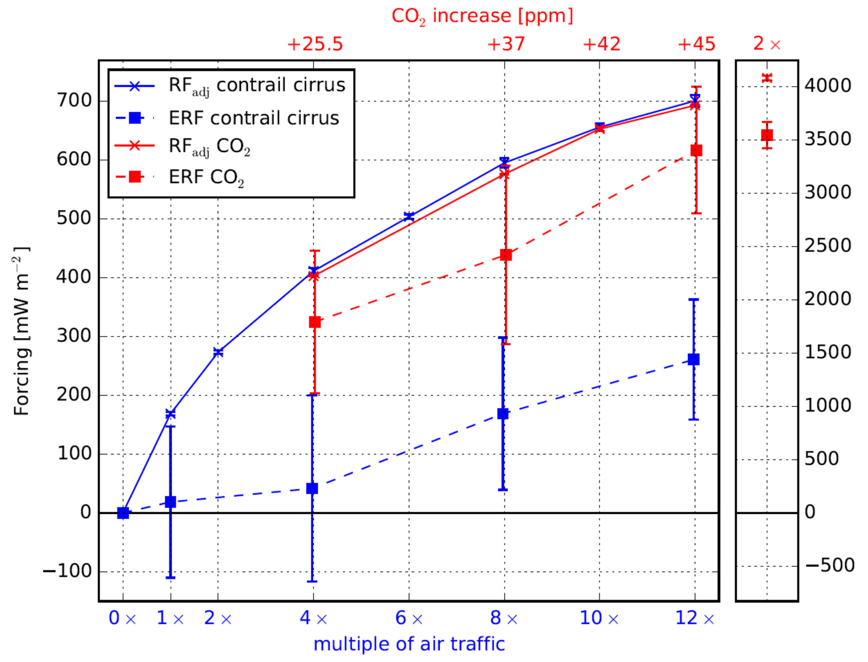
Previous climate model simulations indicate that the efficacy of RF_{adj} of line-shaped contrails in forcing surface temperature is significantly reduced (Ponater et al., 2005). Thus RF_{adj} may be not the ideal metric for assessing the climate impact of contrails. Here, we focus on the more relevant contrail cirrus climate impact using a state-of-the-art methodical framework. We performed RF_{adj} and effective radiative forcing (ERF) simulations after the fixed sea surface temperature method (FSST) as recommended by Forster et al. (2016). In a subsequent feedback analysis we determine the rapid radiative adjustments which are responsible for a potential reduced ERF.





Compared to common CO_2 doubling simulations the RF of contrail cirrus is relatively small. In order to achieve significant results for the ERF it was essential to scale air traffic. The left Fig. shows the relative increase of contrail cirrus cover when scaling 2050 air traffic by a factor of 12. The contrail cirrus cover increase is largely anti-correlated with air traffic density. Thus, an increase of air traffic along the main flight routes hardly affects the contrail cirrus cover.

Scaling Experiments

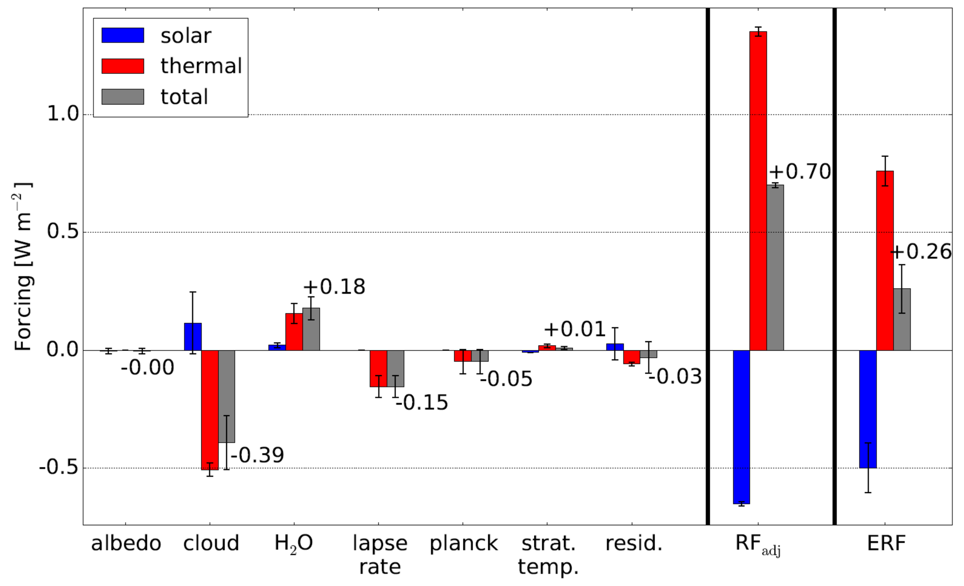


RF_{adj} (blue solid line) and ERF (blue dashed line) simulations were performed for different scalings of air traffic. RF_{adj} is growing non-linearly. For a 12× scaling of air traffic the RF_{adj} only increases by a factor of 4.1. Furthermore, the ERF is reduced to about 37% compared to RF_{adj}. This strongly suggests that the climate impact of contrail cirrus is largely reduced. Note that the scaling of air traffic is needed to achieve ERF values that are significantly larger than zero.

In order to evaluate our model against literature we also performed CO_2 increase simulations. The CO_2 concentrations where chosen so that the RF_{adj} of CO_2 (red solid line) match the respective RF_{adj} of air traffic. The ERF simulations of CO_2 (red dashed line) use identical CO_2 concentrations. The ERFs of CO_2 are also reduced but only significantly lower than RF_{adj} for a 2 × CO_2 increase (see right box). Overall the reduction of ERF is much weaker for CO_2 than for contrail cirrus.

Rapid Radiative Adjustments of Contrail Cirrus

The partial radiative perturbation (PRP) method (Rieger et al., 2017) has been applied to determine the rapid radiative adjustments of contrail cirrus (left box). The Rapid radiative adjustments are responsible for the large reduction of ERF (right box) compared to RF_{adj} (mid box). ERF is largely the sum of RF_{adj} and the various rapid radiative adjustments. The PRP calculations are based on the 12× air traffic ERF simulation.

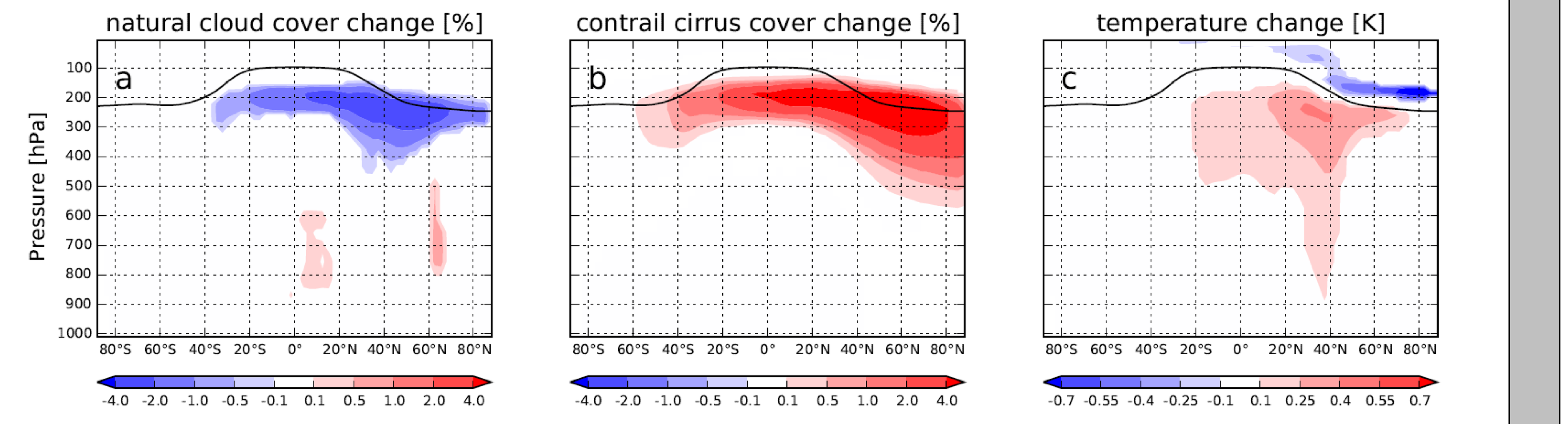


A large negative natural cloud adjustment (-391 mWm^{-2}) was found to be the main driver of the ERF reduction in the contrail cirrus case. The positive water vapor adjustment is almost completely compensated by the negative lapse rate adjustment. The non-zero planck adjustment is a result of the FSST method where land surface temperatures are not fixed. Albedo and stratospheric temperature adjustment hardly contribute to the reduction of ERF.

Conclusions

- **Contrail cirrus cover approaches saturation in regions of high air traffic density**
- **Effective radiative forcing of contrail cirrus is reduced by more than 50% compared to the classical radiative forcing (RF_{adj})**
- **For CO_2, an effective radiative forcing reduction shows up as well, but by far less distinct (~10%)**
- **Calculation of rapid radiative adjustments explains the reasons for the difference between effective and classical radiative forcing**
- **Presence of contrail cirrus reduces the natural cirrus cover, leading to substantial compensation effects**
- **Reduced ERF of contrail cirrus suggests a reduced impact on surface temperature change**

Cloud Cover and Temperature changes

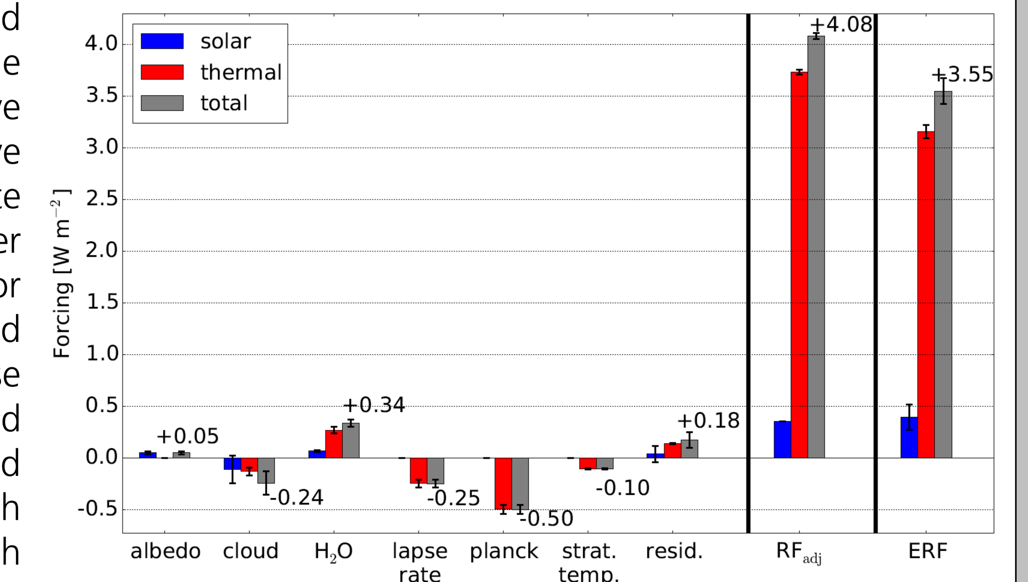


The increase of contrail cirrus cover (Fig. b) is partly compensated by a loss of natural cirrus cover (Fig. a). This compensation effect was found to be the main reason for the large negative cloud adjustment and thus for the reduced ERF of contrail cirrus.

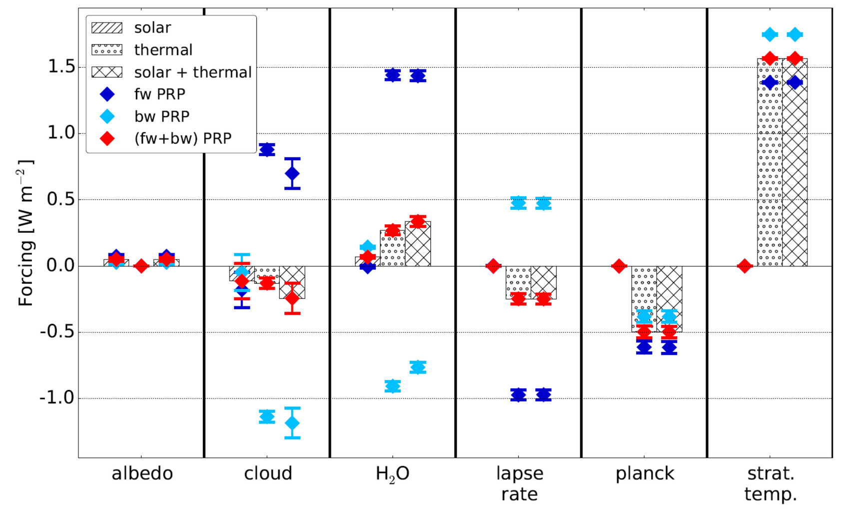
The warming of the upper troposphere (Fig. c) leads to a negative lapse rate adjustment through increased longwave emission and to a positive water vapor adjustment.

Comparison with 2 × CO_2

In the CO_2 doubling experiment the land surface temperatures increase noticeable which leads to a relatively large negative planck adjustment and a slightly positive albedo adjustment. The lapse rate adjustment is compensated by the water vapor adjustment much stronger than for the contrail cirrus case. The cloud adjustment is negative due to an increase of low level clouds between 45°S and 45°N. All adjustments except the cloud adjustment are in good agreement with literature (see Vial et al., 2013 and Smith et al., 2018).



A en passant finding: forward / backward CO_2 radiative adjustments



A closer look at the results of the PRP method revealed that the respective forward (dark blue) and backward parts (light blue) show a large divergence (even in sign). This behavior is largely consistent with Rieger et al. (2017) and confirms that it is essential to use the centered version of the PRP method (red). However, in literature the computational cheaper Kernel method is preferentially applied. Kernels are most likely set up in a way that corresponds to the forward calculation of the PRP method, by using a perturbation added to the reference state. That might be one reason for our deviating cloud adjustment, but however further research is needed on this topic.

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